

## **Chapter 18**

### **Structural Solutions for Navigation Projects**

#### **18-1. General**

Ice problems at navigation locks and dams have been identified and grouped into ten categories. These are discussed in Chapter 14. Floating brash ice hinders normal lock operations and can delay barge movements for hours. Floating ice accumulations are often difficult to pass through dams to downstream reaches where the ice may pose fewer operational problems. Ice adhering to various lock surfaces interferes with the operation of lock machinery and can restrict the usable width of lock chambers. All of these problems can be addressed by various structural solutions which are discussed in this chapter.

##### *Section I*

##### *Floating Ice Dispersion*

#### **18-2. Introduction**

The most notable problems with brash ice are its entry into lock chambers, sometimes in heavy enough quantities to require separate ice lockages to pass the ice downstream, and its accumulation in miter gate recess areas, preventing the full opening of the gates. The most successful way to disperse ice is by means of high-flow air systems (Rand 1988). These systems may have up to three separate components, each with a specific function that increases the ease of lockage operations. (High-flow air systems are outgrowths of air bubbler systems intended to promote thermal thinning and weakening, i.e., melting, of ice; the latter are discussed in Part I, Chapter 3.)

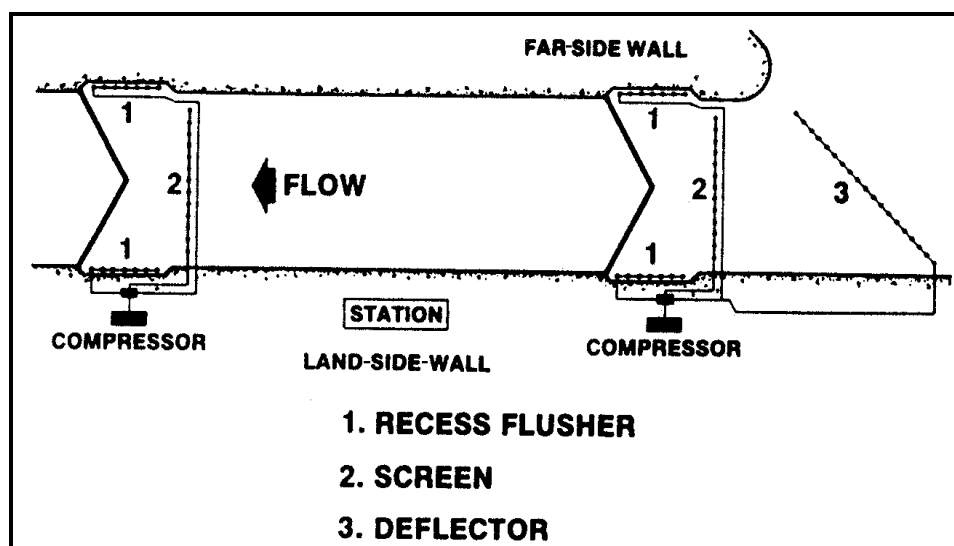
#### **18-3. High-Flow Air Systems**

*a. Distributed systems.* Air manifolds should be placed in three specific locations around a lock to completely mitigate the problems of brash ice (Figure 18-1). First, a recess flusher should be placed in each gate recess; this will clear the recess area. The second manifold, called the screen, should be located just upstream of each set of miter gates. At the upstream edge of the gate forebays, there is typically a sill that runs across the lock chamber; place the screen on the downstream side of that sill. This screen keeps brash ice from entering the lock or, in the case of the downstream screen, clears ice from an area across the width of the chamber before the gate recess flushers are used. The third component is an optional one, depending on the physical layout of the lock and dam project. When there is some means for passing ice through or over a nearby spillway, the addition of a diagonal deflector in the upper lock approach can be an effective way to direct the floating ice toward the spillway. This manifold is typically installed using divers and weights because the area cannot normally be dewatered.

*b. Single-point systems.* Single orifices can be placed on the back wall of a floating mooring bitt recess. A single air line discharging at the bottom of the recess provides sufficient water turbulence to prevent floating ice from being pushed and packed between the float and the recess walls.

#### **18-4. Air System Components**

Each of the major components of high-flow air systems are discussed to clarify what is required and to provide information on physical size and placement of the components.



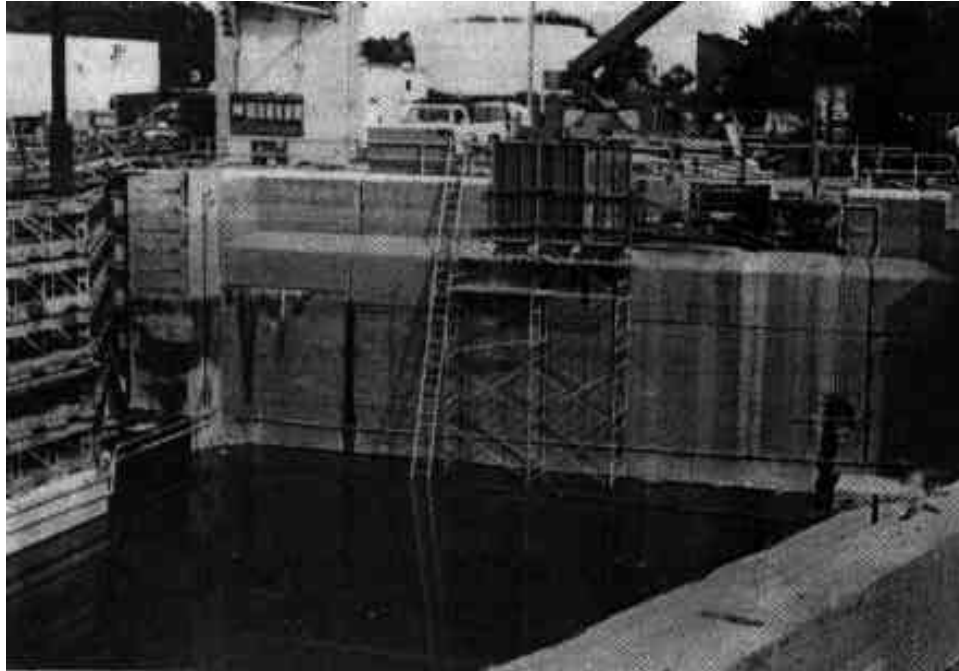
**Figure 18-1. Schematic diagram of a complete high-flow air system, showing the three locations for air manifolds at a typical lock.** *Two compressors are shown, but one large compressor with long supply lines could also be employed, assuming the supply lines are adequately sized*

*a. Compressor.* The air compressor of the size required is generally either diesel-powered or electrically operated. It can be either a permanent fixture or rented for the winter months. In a complete high-flow air system, the component requiring the most amount of air is the diagonal deflector. For a 33.5-meter-wide (110-foot-wide) chamber, a diagonal deflector manifold length of at least 61 meters (200 feet) is required. Design calculations (paragraph 18-6) will indicate that a compressor of at least 21.2-m<sup>3</sup>/min (750-ft<sup>3</sup>/min) capacity must be available. No more than one manifold should be used at any one time.

*b. Supply lines.*

(1) Pipes that run from a single, centrally located compressor to each end of the lock chamber must be large enough to handle the necessary air flow. One of the most common mistakes in designing an air system is undersizing the supply lines. Typically, at least a 7.6-centimeter-diameter (3-inch-diameter) schedule 40 pipe should be considered. If a supply length of over 152 meters (500 feet) is required, then a 10.2-centimeter (4-inch) pipe should be used for at least part of the total distance. Air control valves should be located at each end of the lock. Ideally, they should be remotely operated for easy use by the lock operator. The control valves allow the operator to selectively choose which air manifold to operate at any given time. An indicator should be provided to assure the operator that the valves are operating correctly.

(2) Supply lines from the control valves to the air manifolds submerged in the lock chamber vary in size, depending on the location of each manifold. The gate-recess flusher manifolds on the land wall require only a 5.1-centimeter (2-inch) pipe as a supply line (Figure 18-2). The gate-recess flusher manifold on the river wall, because of the added distance across the lock chamber to the manifold, needs to have at least a 7.6-centimeter-diameter (3-inch-diameter) supply line until the supply line reaches the far side of the lock chamber. The air screen going across the forebay sill requires at least a 7.6-centimeter (3-inch) supply line because of the volume of air being delivered (Figure 18-3). The location and placement of the supply lines may vary from lock to lock. It is best if the pipes can be located within the concrete walls,



**Figure 18-2. A flusher on the land wall of the upper gate recess composed of a supply line and the manifold with orifices at Peoria Lock on the Illinois Waterway.** *Note the vertical supply lines for the recess flusher of the river wall gate and for the cross-chamber air screen installed on the downstream-facing surface at the left (upper) end of the gate recess*

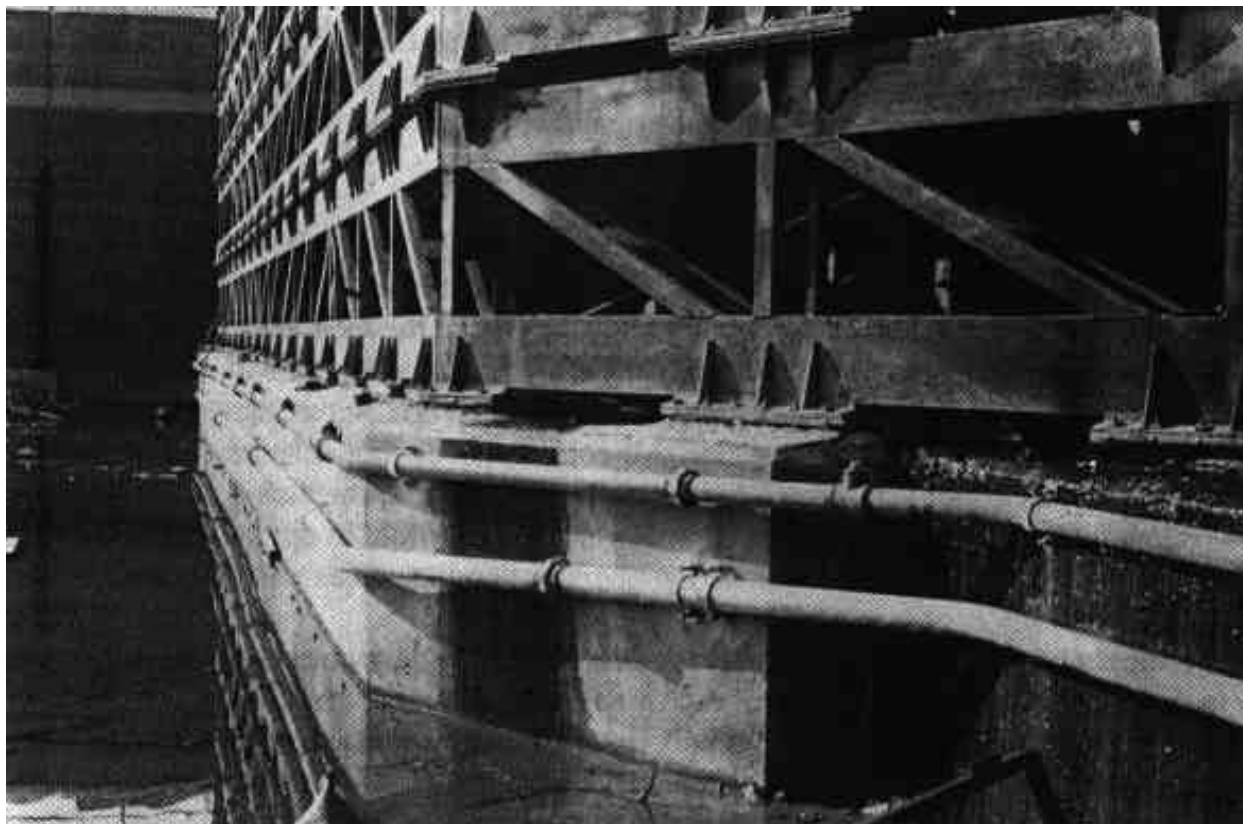
but if this is not possible, they should be located along the upstream edge of the gate-recess wall, protected from floating ice by steel plating.

*c. Check valves.* At the bottom of the vertical leg of each supply line entering the lock chamber, an in-line, spring-loaded check valve should be installed to prevent water from passing into the manifold through the orifices, entering the supply pipe, and freezing near the water surface when the air lines are shut off. This check valve must be removable by divers for replacement or repair if required.

*d. Manifolds.* The manifolds for each of the systems vary with the number of orifices and the size of the pipe. The design of an air manifold should provide for an even and uniform air flow through its entire length. To achieve this goal, the total area of the orifices must be less than 25 percent of the cross-sectional area of the manifold.

*e. Recess flushers.* The gate-recess flusher manifold differs from the other air manifolds because of the orifice spacing and pipe size. Laboratory and prototype analyses have shown that the spacing of the orifices should vary to provide more air near the quoin or pivot of the gate. The nominal spacings between orifices starting at the quoin end of the gate should be 1.2, 1.2, 1.2, 1.8, 2.4, 3, 3, and 3 meters (4, 4, 4, 6, 8, 10, 10, and 10 feet). The actual length of the manifold may vary because of lock constraints. Typically, in the locks on the Illinois Waterway, nine orifices are used.

*f. Screens.* The manifolds for the sill screens are designed with a 2.4-meter (8-foot) orifice spacing. For locks with a width of 33.5 meters (110 feet), a 29.3-meter-long (96-foot-long) manifold is used; 13 orifices are placed along that manifold.



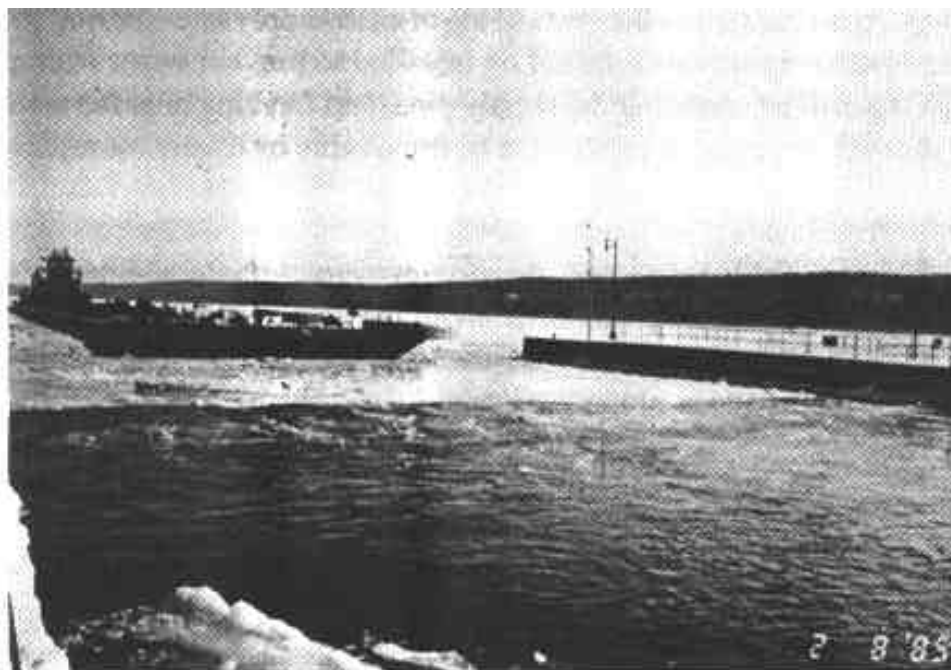
**Figure 18-3. Downstream side of forebay sill, Peoria Lock.** Air-screen manifold (top pipe) and supply line for river wall gate-recess flusher (bottom pipe) are attached to the sill face with U-straps. There is an orifice at each pipe tee location in the manifold

*g. Deflector.* For a diagonal deflector in the upper lock approach area, a 61-meter (200-foot) manifold is recommended, with 26 orifices.

*h. Orifices.* Each orifice is a drilled hole in a hex-head stainless steel pipe plug, which is installed in a pipe tee in the manifold line. The inside of the plug is slightly chamfered, and there is a sharp edge at the outside surface. The orifices are aligned so that the air discharges vertically. Occasionally, the orifices might become plugged with silt, so the manifold should be regularly operated throughout the year to help the orifices remain free of dirt. The orifice diameter ultimately controls the amount of air discharged. From laboratory analysis, it is recommended that a design flow of 0.85 m<sup>3</sup>/min (30 ft<sup>3</sup>/min) be provided for each orifice. This will provide sufficient air to create the desired effect at the water surface. For all the systems installed on the Illinois Waterway, 0.95-centimeter-diameter (3/8-inch-diameter) holes were drilled in the pipe plugs to serve as the orifices.

### 18-5. Effectiveness of the Air Systems

Experience gained from the use of complete high-flow air systems, as described above, has shown that the systems reduce winter lockage times, make for a safer operation, and keep the morale of lock personnel high. An average of 1 hour of compressor time is required to lock through an average tow. Some variation is experienced between individual operators, but all agree that a high-flow air system is an effective way to control floating ice problems at a lock (Figures 18-4 and 18-5).



**Figure 18-4. Upper screen in operation at Starved Rock Lock, Illinois Waterway.**  
*Most brash ice is prevented from entering lock chamber, even with the entry of downbound tows*

## 18-6. Design of a High-Flow Air System

The parameters affecting the design of a high flow air system include: air volume and pressure available; effective length and size of the supply line; length and size of manifold line; depth of submergence; and orifice size and spacing. The air system analysis determines air discharge rates from an orifice by an iterative scheme that starts with a trial dead-end pressure. The analysis calculates the orifice discharge and pressure, starting from the end and working toward the supply point. After all the orifices are analyzed, the supply line pressure and air flow are calculated. The compressor pressure and flow rate necessary to sustain the supply line pressure and air flow are then calculated. The calculated compressor output is compared to the actual compressor output. The trial dead-end pressure is then adjusted and the analysis scheme repeated until the calculated and specified compressor outputs differ by no more than 1 percent. Changes in system parameters are made until the optimum design is obtained.

*a.* The calculations for optimizing the air system parameters are provided below. The initial trial dead-end pressure ( $P_d$ ) is taken as

$$P_c = P_v + \frac{(P_u - P_v)}{4} \quad (18-1)$$

where

$P_c$  = true compressor pressure

$P_w = \rho_w g H$  = hydrostatic pressure



**Figure 18-5. Gate-recess flusher in operation at Starved Rock Lock.** *The ice is flushed away from the recess area, allowing the miter gate to be fully opened*

$\rho_w$  = mass density of water

$g$  = gravitational constant

$H$  = submergence depth.

The subsequent trial dead-end pressure ( $P_d$ ) is determined by

$$P_{d(new)} = P_v + (P_{d(old)} - P_v) \left( \frac{P_u - P_v}{P - P_v} \right) \quad (18-2)$$

where

$P$  = calculated compressor pressure

$P_{d(old)}$  = old trial dead-end pressure

$P_{d(\text{new})}$  = new trial dead-end pressure.

The air discharge rate ( $Q_o$ ) from the orifices is calculated by the discharge equation

$$Q_o = C_d \frac{\pi d^2}{4} \sqrt{2\Delta P / \rho_a} \quad (18-3)$$

where

$C_d$  = discharge coefficient, sharp-edged circular orifice

$d$  = orifice diameter

$\Delta P$  = pressure difference between inside and outside of diffuser line

$\rho_a$  = mass density of air.

Finally, the pressure drop attributable to friction between orifices and in the supply line ( $\Delta P_f$ ) is calculated using the friction loss equation for turbulent flow conditions

$$\Delta P_f = \frac{f \rho_a \ell v^2}{D} \quad (18-4)$$

where

$f$  = friction factor

$\ell$  = equivalent length of pipe

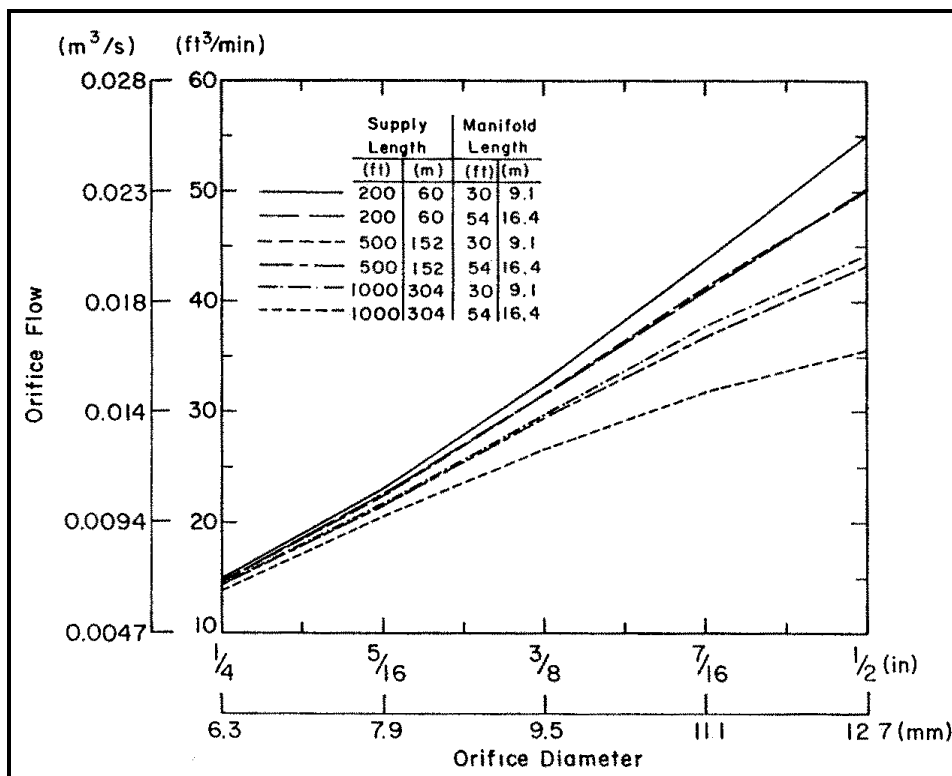
$v$  = air velocity

$D$  = pipe diameter.

*b.* A computer program analyzing diffuser lines and nozzles gives a numerical simulation of air bubbler systems and is used for the air screen analysis. The input data include: diffuser line length and diameter, supply line length and diameter, orifice diameter and spacing, nominal compressor pressure, and submergence depth. The output from the program lists the following parameters: hydrostatic pressure, calculated output pressure, calculated compressor discharge, friction drop in diffuser line, friction drop in supply line, and excess dead-end pressure. To illustrate how changes in the system parameters affect the operating characteristics, Figures 18-6 and 18-7 show the effect on changes in the flow through an orifice with respect to changes in orifice diameters.

### 18-7. Example

A compressor with an output of 0.543 m<sup>3</sup>/s (1150 ft<sup>3</sup>/min) at 759 kPa (110 lb/in<sup>2</sup>) was available for the high-flow air screen trials at the Soo Locks. Optimum air flow conditions could be obtained from a 5.1-centimeter-diameter (2-inch-diameter) manifold and supply line system with nozzles of 10-millimeter

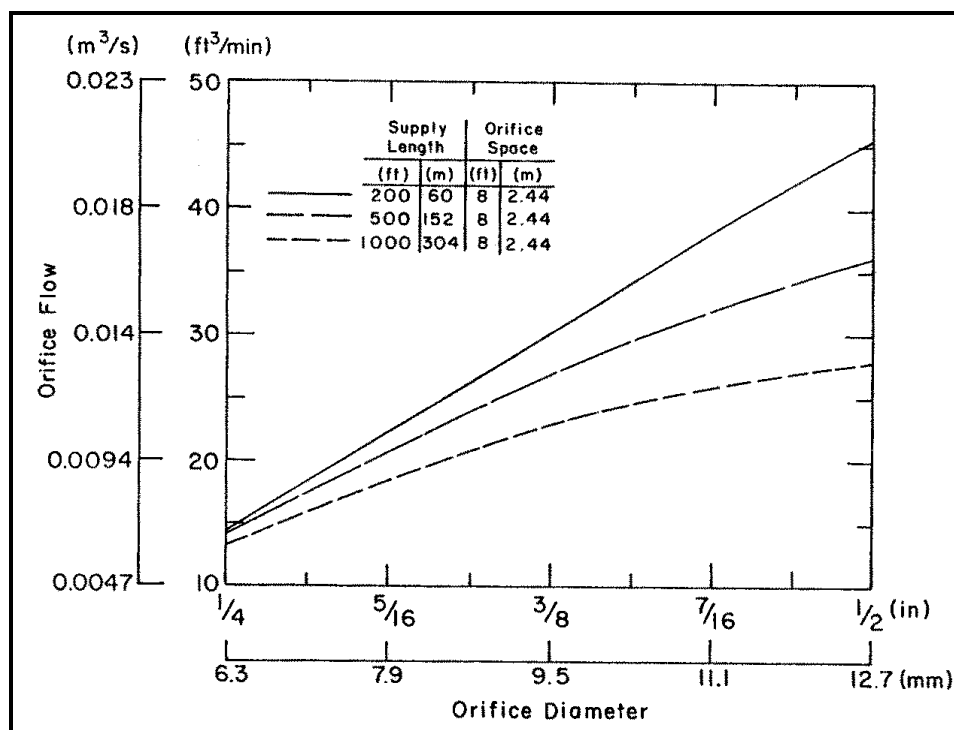


**Figure 18-6. Performance curves for gate-recess flushers, showing the average air discharge from each orifice plotted with respect to orifice diameter, for combinations of three supply-line lengths and two manifold lengths.** The 5.1-centimeter (2-inch) diameter manifolds are either 9.1-meters (30-feet) nominal length for 17.1-meter (56-foot) wide locks, or 16.5-meters (54-feet) nominal length for 33.5-meter (110-foot) wide locks, submerged 6.1 meters (20 feet) below the water surface. Six orifices at nominal spacings of 1.2, 1.2, 1.2, 1.8, and 2.4 meters (4, 4, 4, 6, and 8 feet) are present in the 9.1-meter (30-foot) manifolds, and three additional orifices at nominal 3.0-meter (10-foot) spacings are present in the 16.4-meter (54-foot) manifolds

(0.40-inch diameter), spaced 3 meters (10 feet) apart. The manifold line was 5.1-centimeter (2-inch) galvanized pipe with 5.1- × 5.1- × 2.5-centimeter (2- × 2- × 1-inch) tee joints each 3 meters (10 feet) of pipe. A 2.5-centimeter (1-inch) stainless steel plug was mounted at each tee and each plug had a 10.3-millimeter (0.406-inch) hole drilled in it that acted as the nozzle or orifice. The supply line riser, which ran up the side of the lock, was also of 5.1-centimeter (2-inch) galvanized pipe. A flexible, quick-disconnect hose joined the bottom of the riser to the horizontal manifold line. Flexible hose was also used from the top of the riser to the compressor.

a. The high-flow air screen was installed at the upper approach to the Poe Lock on the downstream, vertical face of an emergency stop-log gate sill. The sill is located about 61 meters (200 feet) above the lock gates. The riser line was installed in the stop-log recess in the wall. The width of the lock at this point is 33.5 meters (110 feet) and the height from the top of the sill to the top of the lock wall is 11.9 meters (39.2 feet).





**Figure 18-7. Performance curves for an air screen, showing the average air discharge from each orifice plotted with respect to orifice diameter, for three supply-line lengths.** The 6.4-centimeter (2.5-inch) diameter, 29.3-meter (96-foot) long manifold is typical for a 33.5-meter (110-foot) wide lock, and has 13 orifices at 2.4-meter (8-foot) spacings, 6.1 meters (20 feet) below the water surface

b. The manifold line was installed at a depth of 10.5 meters (34.5 feet) in December 1977 and was assembled into four sections: two sections 8.46 meters (27.75 feet) long and two sections 7.47 meters (24.5 feet) long. Union connections joined the sections. The riser was assembled in one 11.7-meter (38.5-foot) section. The sections were light in weight; two to three people were able to move them by hand. All equipment for a hard-hat diver and the assembled pipes were placed on a 30.5-meter (100-foot) barge that acted as the working platform. The barge was positioned above the sill, and sections were lowered on ropes to the diver below who made the union connections and strapped the line to the concrete sill (Figures 18-8 and 18-9). One flexible hose coupling, from the diffuser to the riser, was also made underwater. The above-water installation process consisted of simply connecting a 15.2-meter (50-foot) flexible hose from the top of the riser line to the compressor. A 37,900-liter (10,000-gallon) fuel tank was placed beside the compressor to supply fuel (Figure 18-8) throughout the winter when delivery would be difficult.

c. The high-flow air screen was put into operation on 12 January 1978 when ice started to cause problems with lock operations. It was continuously available for service until 30 April 1978, except for a 5-day repair period in late March. By 1 May, ice no longer caused problems requiring the air screen, and the rented compressor was returned. During the 104 days of operation, the total running time on the compressor was 754 hours. Total consumption of No. 1 fuel oil was about 29,300 liters (7750 gallons).

d. The high-flow air screen demonstrated that it could hold back ice pushed ahead of downbound traffic. With ships in the 21.3-meter (70-foot) beam class, the ice was held back until the bow entered the air stream. The screen was not as effective with the wider 32-meter (105-foot) beam ships. Once the



**Figure 18-8. Diver working to install air screen system**

bow of a wider vessel passed the nose pier (about 40 meters [130 feet] upstream of the screen), the approach was just a little over 33.5 meters (110 feet) wide, so most of the ice remaining in the track was pushed into the lock by these larger ships. This problem possibly could have been solved by relocating the air screen upstream of the nose pier area and by providing some area for the ice to be pushed outside the vessel track.

*e.* The merits of the air screen cited by lock operating personnel, besides the reduction in vessel lockage time, were savings in wear and tear on the lock gate and operating mechanisms, and savings in the time and effort required to remove ice collars from the lock walls. (The ice collars at the Soo result in part from the vessels packing brash ice against the lock walls.)

### **18-8. Flow Inducers**

A common technique to move ice in and around the lock is the use of a towboat's propeller wash to induce a flow that moves the brash ice. The towing industry assists itself and the Corps lock personnel on occasion; towboats break away from their tows and flush sections of a navigation project. Another type of flow inducer used in the past, a submergible mixer, develops a flow in the top layer of the water to aid in moving debris or floating ice. An example of this operation formerly existed at the Chicago Harbor Lock, where submergible mixers were attached near the sector gates. However, they have been removed. To prevent ice from accumulating in front of lock miter gates that are not functioning during the winter months, several Districts have made use of commercially available flow inducers designed for the marina industry for protecting docks.

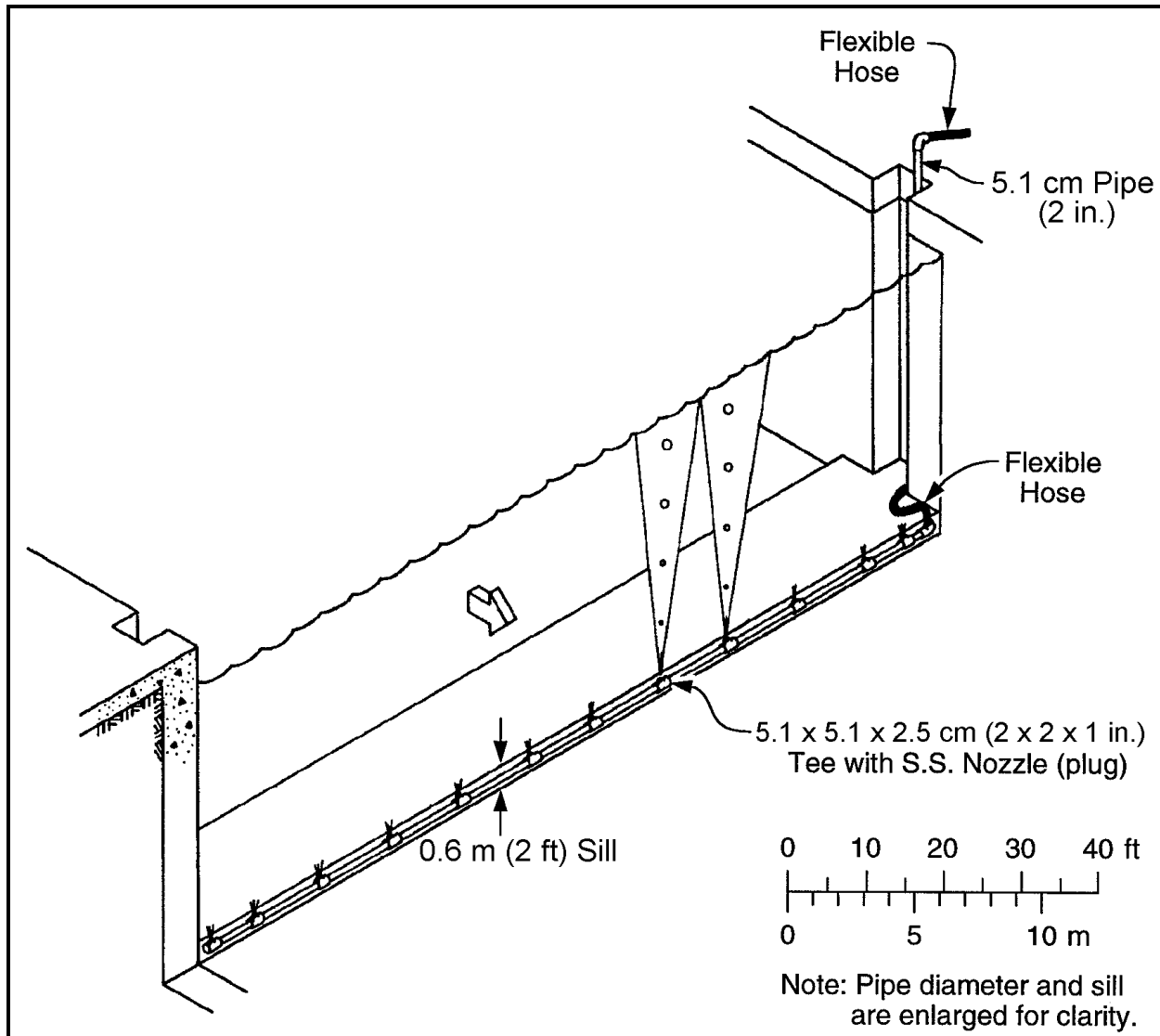


Figure 18-9. Schematic of an air screen

## Section II

### Ice Passage Through Dams

#### 18-9. Introduction

The question of holding ice or passing ice from one navigation project to the next is a subject of great concern on all river systems. A definitive position on this problem cannot be taken. It is clearly understood that growing a stable ice cover will reduce the overall quantity of ice grown because of the reduction in frazil generation. However, the broken ice within the frozen ship track has to be dealt with every time a vessel passes through. Just upstream of the locks is a particularly unfavorable spot to allow ice to accumulate. Almost every lockmaster will state that he wants to keep that zone above his lock clear. The specific policy, however, will have to be addressed in each of the river systems.

### **18-10. Submergible Tainter Gates**

A case study of use of submergible gates at Corps projects was prepared by the Louisville District (U.S. Army 1985). Each of the project sites discussed in the study has a variety of dam gates. In the past, the use of submergible gates to pass ice in the former North Central Division was encouraged, whereas the former Ohio River Division did not allow the existing submergible gates to be operated. (These former separate divisions are now represented by the Great Lakes and Ohio River Division and by a portion of the Mississippi Valley Division.) The specific problems and comments regarding the varied use of submergible gates are well documented in the Louisville report. Figure 18-10 summarizes many of the submergible gates considered in the study. A recent rehabilitation project on the Illinois Waterway installed submergible gates at Marseilles Dam specifically for improving ice passage. The major problem with passing ice is having sufficient water flow in the river system to open the gates, while maintaining adequate river stage. If broken ice is flowing toward the dam and the gates can be opened, a submergible gate will pass more ice than a nonsubmergible gate, given the same conditions. But it is more common that there is insufficient surface velocity to move ice toward the gate area. When this is true, the better ice passage characteristics of submergible gates provide no benefit. Moreover, ice bridging upstream of the gate, between the dam piers, is a common problem. However, a benefit of using submergible gates is that, since the gate is kept under the water, many gate freezeup problems are eliminated.

### **18-11. Roller Gates**

Roller gates are used extensively on the Mississippi River. At some projects they are lowered to a fixed submerged setting in the late fall and are kept in that position for the duration of the winter. The pools are then maintained by adjusting tainter gates. At other projects, the tainters are left to freeze in and the roller gates are adjusted, either submerged or with a bottom opening, to maintain upper pool stages. (At Lock 10 in the St. Paul District, the roller gates are not designed to be submergible, but they are the operative gates in winter.) In the cases where the roller gates are used in the submerged mode in winter, they may assist in ice passage, functioning in the same manner as submergible tainter gates, but having the same limitations. Other problems associated with roller gates are largely related to the lifting mechanisms, in which ice interferes with lifting chains, guide channels, and gear racks.

### **18-12. Conventional Tainter Gates**

The openings required for ice passage at conventional tainter gates are usually quite large owing to the very high flow velocities needed to sweep floating ice downward to the bottom openings. As a result, except during periods of flood flow, these large openings normally cannot be used because of the likelihood of downstream scour at low tailwater stages. Thus, during the customary low-flow conditions of the winter season, ice passage at these gates is not feasible.

### **18-13. Gate Limitations in Winter**

As detailed in Chapter 14, paragraphs 14-4g through *i*, successful operation of dam gates in winter, regardless of gate types, is impeded by accumulated forebay ice, by ice buildup on gate and pier structures from spray and splashing, and by the freezing of leakage past gate seals. All of these factors combine to render ice passage through gate bays very difficult and unreliable, unless remedial measures, as discussed in the following section, are employed.

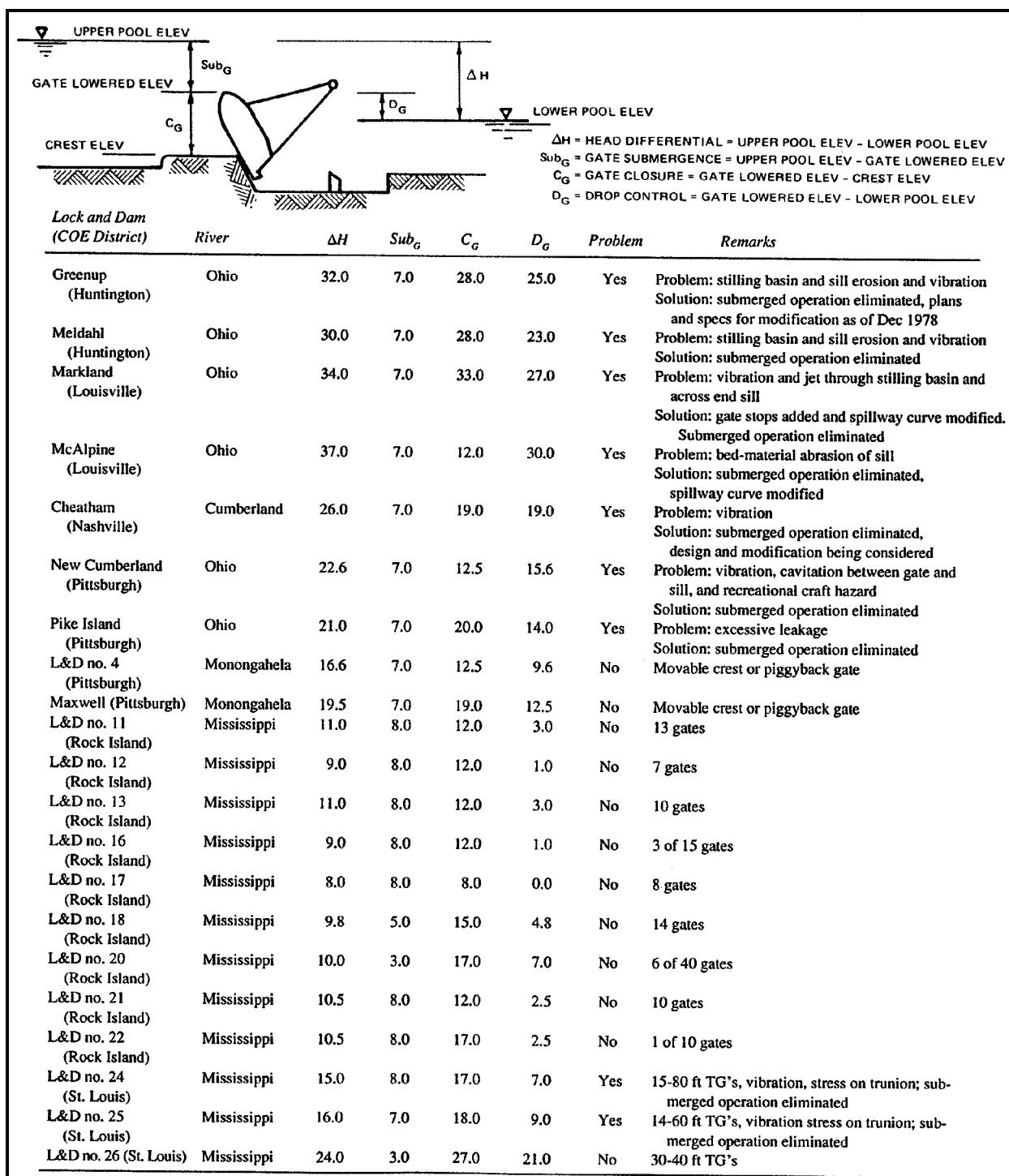
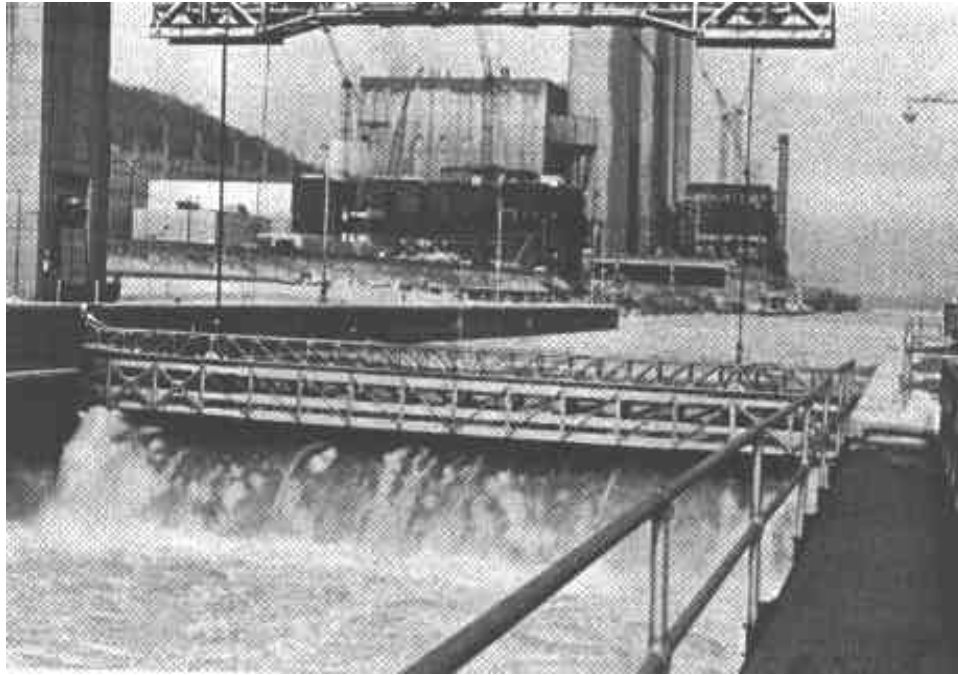


Figure 18-10. Summary of submergible gates and their problems. Many of these were considered in the Louisville District study of the use of submergible gates for passing ice (U.S. Army 1985)

## 18-14. Other Ice Passage Schemes

Ice can be successfully passed at some navigation locks having auxiliary lock chambers and bulkhead lift systems by skimming the ice over partially raised bulkheads. Figure 18-11 shows such an operation. This appears to be an effective way to pass ice through the lock system, thus clearing the upper approach area.



**Figure 18-11. Ice passage at New Cumberland Lock on the Ohio River.** *The partially raised bulkhead of the auxiliary lock chamber allows flow to carry ice out of the lock approach area*

### *Section III* *Anti-Icing and Deicing at Locks and Dams*

## 18-15. Introduction

As described in Chapter 14, the ice-related problems at navigation structures are severe during the winter months. Exposed mechanically operated systems may be frozen-in and become inoperable. The weight of ice formed on structures that need to be lifted or moved may become excessive so that the system becomes overloaded. Ice loads can also cause structural damage. Icing on the recess walls or gates of navigation locks prevents full opening of the gates. Ice formation on the chamber walls prevents full use of the lock width. Ice buildups on dam pier walls can obstruct the movement of the components of dam gates. Ice in any form causes safety hazards for personnel working on or near it. All of these ice problems involve ice formation on or adhesion to critical surfaces at locks and dams. Solutions to these ice problems at navigation projects currently are time-consuming and expensive. This section addresses several approaches to solving the problems of surface ice formation and adhesion.

## 18-16. Electrical Heating of Lock and Dam Components

Ice adhesion on walls can be prevented by maintaining wall temperatures above 0°C (32°F), or ice collars can be shed periodically by raising the wall temperature intermittently. Possible arrangements include embedded (but removable) electrical heating cables within walls, direct placement of heat mats on walls, and heating dam gate side J-seals.

*a. Embedded electrical heaters.* The use of embedded electrical heaters that cannot be removed for replacement without major rehabilitation is *not recommended*. Almost every navigation project that has installed embedded electrical heaters has some heaters that have failed and cannot be replaced. The recommendation for those areas where embedded heaters are needed is a replaceable heat tape as described here. During a rehabilitation project, where the concrete walls are to be resurfaced, 1.9-centimeter-diameter (3/4-inch-diameter) stainless steel pipes should be installed, 15 to 20 centimeters (6 to 8 inches) on center, with the bottom ends sealed. At the top of the pier or along the top of the wall, the top ends of the pipes are accessible so that electrical leads can be run from one vertical pipe to the next. The tubes are filled with glycol to act as a heat-transfer fluid, once the self-regulated heat tape is inserted into the pipe. The heat tape can be cut to specific lengths by project personnel and inserted into the pipe. The heat tape is self-regulating and has an output of 121 W/m at 0°C (37 W/ft at 32°F). In the control circuit, timers and thermostats can be added to limit power consumption. If a heat tape fails, then a new length of heat tape may be cut and installed. The cut end should be sealed using heat-shrink tubing, and a cold electrical lead is added to the upper end. Alternate techniques of installing the pipes are by drilling vertical holes along the edge of a pier or wall (however, a major concern is the possibility of the hole breaking out) and by cutting vertical slots 7.5 to 10 centimeters (3 to 4 inches) deep in the wall.

*b. Wall heat mats.* Fiberglass-reinforced plastic heat mats have been placed directly on a vertical concrete wall at a lock to prevent ice from forming a collar in the gate recess area. The commercially available mats can be provided in any shape or size up to 1.2 × 2.4 meters (4 × 8 feet). Variable power ratings are also available. The mats shown in Figure 18-12 are 1076 W/m<sup>2</sup> (100 W/ft<sup>2</sup>). These panels are each 1.2 × 1.2 meters × 0.6 centimeters (4 × 4 feet × 1/4 inch) thick. The mats are very effective in keeping the wall clear of ice. Material costs (1988) for such a mat material were about \$753/m<sup>2</sup> (\$70/ft<sup>2</sup>).

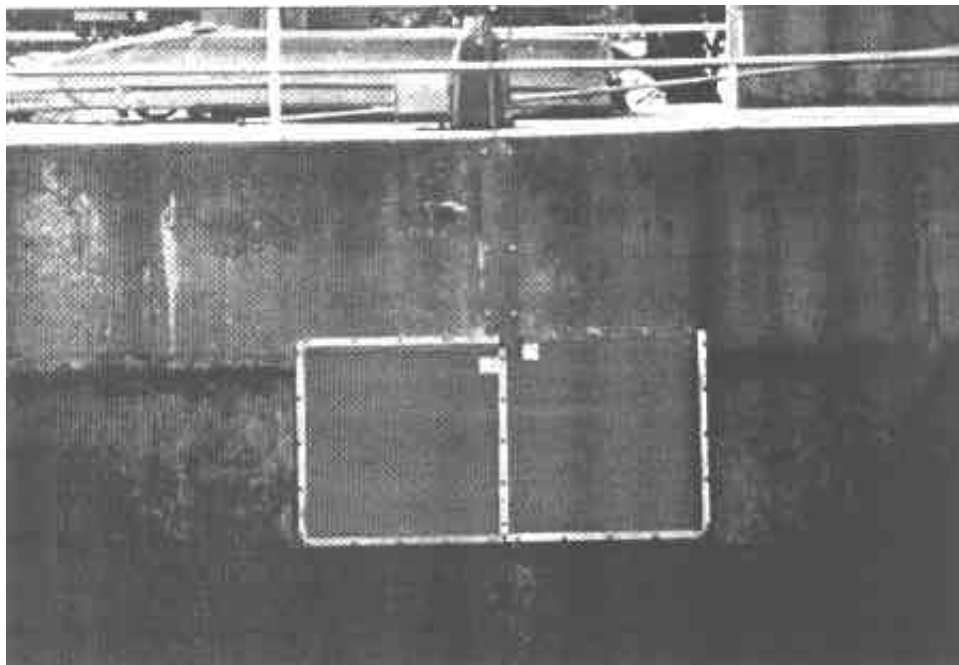
*c. Heated J-seals on dam gates.* Heating the side J-seals improves their ability to reduce leakage past tainter gates, and thus reduce the associated buildup of icing on the walls and the gate structures. This method is easily adaptable at low cost to existing dam gates (using Huntington J-seal Mold No. 3493 or equivalent).

(1) This in situ heating system has been made up so that it can be inserted into the hollow channel of a J-seal; it keeps ice from forming on the seal and increases the flexibility of the seal at lower temperatures. With increased flexibility, the seal better conforms to irregular surfaces, thereby reducing leakage to the downstream side. With little or no leakage, ice formation on the cold, exposed downstream side is substantially reduced. Neither steaming nor “cindering” (i.e., pouring cinders in the water above the locations of the greatest leakages, so that the cinders flow toward the leaks and plug them) were required during tests of the in situ heating system at Starved Rock Lock and Dam on the Illinois Waterway, where it was installed during a recent dam rehabilitation.

(2) The self-regulating heat trace tape, 208 volts ac at 121 W/m at 0°C (37 W/ft at 32°F), was cut from a spool to a length of 5.5 meters (18 feet). The heat tape was sealed at one end. The other end had a cold electrical lead attached to connect to the electrical power. The J-seal and the inserted heater are shown in Figure 18-13. The 1988 cost of Huntington J-seal Mold No. 3493 was \$45.57/meter



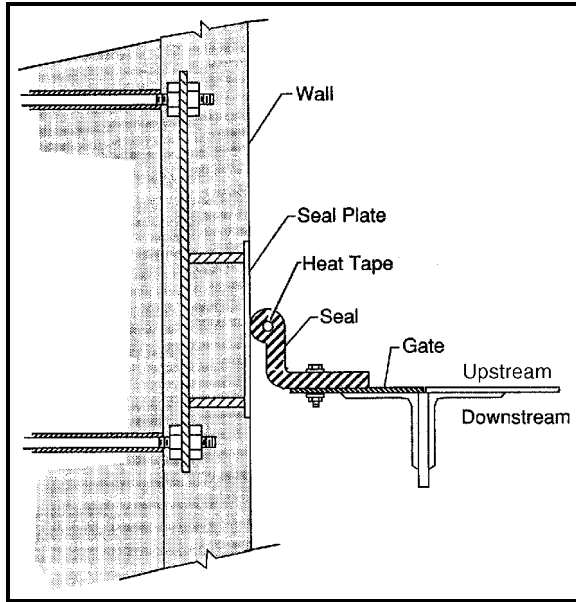
a. General view



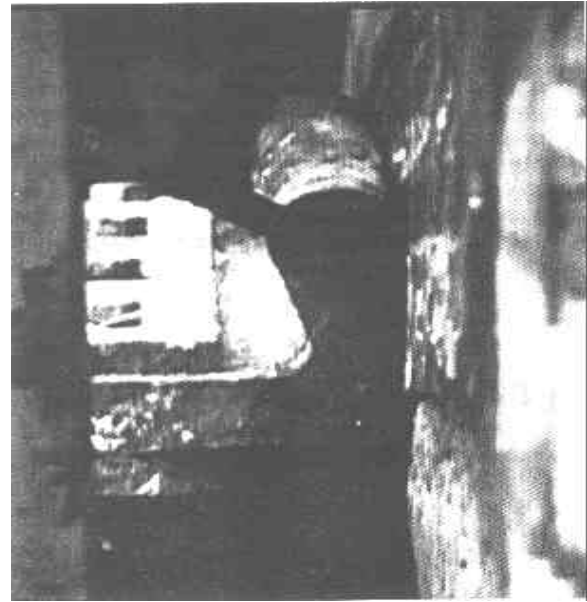
b. Detail showing plate over vertical groove in wall above heat mats, which contains electrical leads

Figure 18-12. Fiberglass-reinforced plastic heat mats installed on a miter gate recess wall at Starved Rock Lock on the Illinois Waterway





a. Diagram



b. Heat tape installed in the hollow channel of a J-seal

**Figure 18-13. J-seal installation on tainter gate**

(\$14.50/foot). The seal was manufactured as of 1988 by Buckhorn Rubber, 55 W. Techne Center Drive, Milford, Ohio 45150 (800-543-5454). The self-regulating heat trace tape is widely available at an approximate 1988 cost of \$16.40/meter (\$5/foot). If both seals of a gate are heated and the heaters are operating at maximum power, the operating cost per day is \$2.24, assuming 1332 watts at \$0.07/ kWhr.

(3) Use of heated J-seals would not preclude the inclusion of embedded electrical heaters in gate pier walls in rehabilitations or new designs, because embedded heaters aid in keeping seal plates ice-free above or below the immediate seal-contact area, so that gates can easily be placed in any chosen position.

### 18-17. Providing Electricity for Heating to Locks and Dams

Electricity for the heating and deicing of lock and dam components can be supplied by the local electric utility. But since such energy is usually expensive, lower-cost sources of electricity are attractive. Two such alternatives are private hydropower projects installed at Corps navigation projects and, possibly, pre-packaged portable hydropower plants.

*a. Installed private hydropower.* It is the policy of the Corps of Engineers to cooperate with the Federal Energy Regulatory Commission in encouraging private interests to develop hydropower potentials at Corps navigation or flood-control dams. In these cases, the Corps usually has rights to certain portions of the power generated at no cost, as long as it is used for the benefit of navigation. In planning for use of this power, it is recommended that the power needs for ice control be considered and that the total power requirements for navigation be conveyed to parties exploring the feasibility of such private hydropower development.

*b. Portable prepackaged hydropower.* In those cases where private power development is not present or not likely to be developed, the use of dedicated, portable, packaged hydropower units as

described below (if they are commercially available) should be investigated and compared to purchased power for meeting the needs of ice control at navigation locks and dams.

(1) A study conducted by the University of Iowa during the River Ice Management Program (Nakato et al. 1992) endorsed electrical heating as an attractive method for controlling ice, and suggested consideration of using a then-unconventional means of generating electricity on-site: prefabricated, portable, packaged power plants. The study described a concept in the development and demonstration stage (in 1988) for low-head micro-hydroelectric power plants. These packaged plants were of two sizes: one producing 500 kilowatts at a net head of 5.5 meters (18 feet) and a discharge of 11.3 m<sup>3</sup>/s (400 ft<sup>3</sup>/s), and the other a 1250-kilowatt unit operating with a 3.7-meter (12-foot) head and 42.5 m<sup>3</sup>/s (1500 ft<sup>3</sup>/s). These plants gain their portability by being barge-mounted. There is an anchored upstream barge providing the water intake, a siphon penstock, and a downstream barge that carries a submergible horizontal turbine. Trunnion-type joints accommodate variations in upper and lower pool stages. There is no major construction involved for these devices to be installed; they can be placed in a variety of dam configurations, for example, in a gate bay of a navigation dam.

(2) Micro-hydroelectric power-plant output potentials, expressed in combinations of discharge, net head, and resulting power output, are listed in Table 18-1.

**Table 18-1**  
**Output Potential of Micro-hydroelectric Power Plants**

Discharge m <sup>3</sup> /s (ft <sup>3</sup> /s)	Power Output (kW) (at 80% efficiency) at Net Heads of:			
	1.5 m (5 ft)	3.0 m (10 ft)	4.6 m (15 ft)	6.1 m (20 ft)
7.1 (250)	85	170	255	340
14.2 (500)	170	340	510	680
28.3 (1000)	340	680	1015	1355
42.5 (1500)	510	1015	1525	2035
56.6 (2000)	680	1355	2035	2710

## 18-18. Mechanical Removal of Ice from Lock Walls

The experimental extension of the navigation season into the winter months on the Great Lakes created ice problems at the Soo Locks. Even under present operating-season schedules, ice poses many problems at the Soo Locks, as well as at many of the lock-and-dam projects on the Ohio River and its tributaries, on the Illinois Waterway, and on the Upper Mississippi River. Ice can adhere to lock walls, building up an ice collar at and below the high pool level, which can interfere with gate opening and closing and interfere with ship passage. For example, ice collars form at the 33.5-meter (110-foot) wide Poe Lock at Sault Ste. Marie, Michigan. Ships of the *Presque Isle* and *Roger Blough* class with their 32.0-meter (105-foot) beams encounter problems when the ice buildup along the walls becomes greater than 0.76 meters (2.5 feet) on each wall. Prior to the development of the ice cutting saw, discussed below, and the copolymer coating (discussed later in paragraph 18-19a), a number of methods were used with varying degrees of success to overcome this problem. Steam hoses work well but are extremely slow and require many man-hours. Backhoes have been used to scrape off the ice collar. This is faster than using steam, but still slow. Since the operator cannot see what he is doing he may miss some ice or scrape too deep and damage the lock wall. A high pressure water jet was able to cut off the ice, but the jet was noisy and somewhat dangerous, and the pressure pump was both expensive and difficult to maintain. The selected solution used a high-

flow air screen (discussed in Section I of this chapter), a copolymer coating, and an ice cutting saw. The ice cutting saw is discussed here.

*a. Ice cutting saw.* CRREL designed and assembled a mechanical cutting system (see Figure 18-14) to remove the ice collars. The unit consisted of two parts: the cutting system, and the drive and propulsion system. The drive and propulsion system was a 48.5-kilowatt (65-horsepower) four-wheel-drive tractor, originally manufactured as a trencher (the tractor could be purchased without the trencher attachment). The drive line for the trencher was modified to accommodate the cutting system by extending the drive shaft and attaching a drive sprocket to its end. While in the cutting mode, the engine powered the shaft and sprocket directly and the drive wheels indirectly through a separate hydraulic drive system, so cutting power and propulsion power could be independently controlled.



**Figure 18-14. Ice cutting saw at Poe Lock**

(1) The cutting system was one used in the coal industry—a thin, 8.9-centimeter (3.5-inch) kerf cutter manufactured at the Bowdil Company of Canton, Ohio. It consisted of a rugged bar and chain with cutting bits attached. The bar was 24 centimeters (9.5 inches) wide to the chain guide, 3.8 centimeters (1.5 inches) thick, and 4.85 meters (15.9 feet) long; it was attached to the drive shaft housing. Movement of the bar was hydraulically controlled. Different kerf and bar thicknesses were used, but earlier tests showed that a narrow logging saw was too flexible.

(2) The bar was grooved to accommodate the sprocket drive chain and cutting bits and had a roller nose tip to reduce friction and wear. Chain tension was controlled by a high-pressure hydraulic cylinder capable of exerting 8 kilonewtons (1,800 pounds) at 68.9 megapascals (10,000 psi). The bar and chain hang about 0.76 meters (30 inches) past the side of the tractor and the drive wheels (see Figure 18-15).

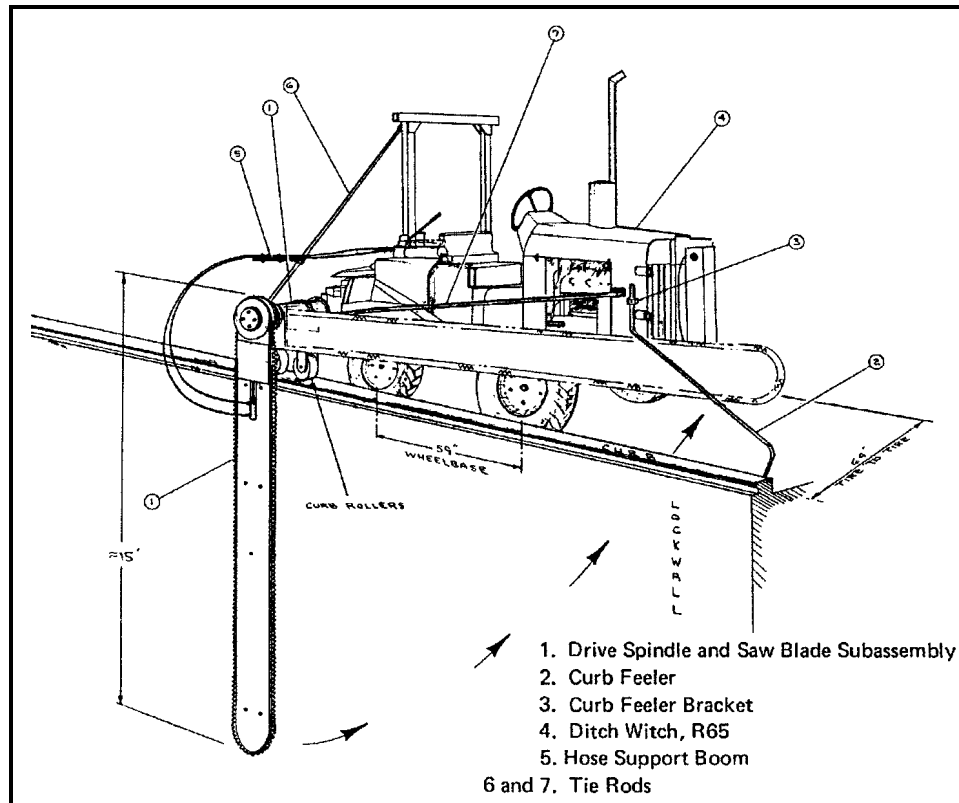


Figure 18-15. Schematic of ice cutting saw

*b. Operation of the ice cutting saw.* When a problem ice collar built up, the esplanade along the lock wall was cleared of snow. The tractor was then positioned with the right wheels close to the curbing along the wall so that there was about 3.8 centimeters (1.5 inches) of clearance between the wall and the bar and chain. A spacer on the wall side of the bar prevented the cutters from damaging the wall. A guide marker located off the right front wheel was positioned and set so the driver could maintain the proper position by keeping the marker and the reference point (top of curb) aligned. Looked at from the driver's point of view, the chain rotated clockwise with the tension cutting side on top of the bar. To start a slot for the bar, the underside of the saw was used until the tip cut completely through the collar. The slot was cut with the tractor stationary. Once a slot was cut through, the bar was placed in a forward position about 70 degrees from the horizontal. Full throttle operation in third gear produced a chain speed of 1.93 meters per second (380 feet per minute), although chain speeds of up to 2.59 meters per second (510 feet per minute) were possible in fourth gear. A traverse speed of over 0.051 meters per second (10 feet per minute) could be maintained while cutting ice collars 1.8 to 2.4 meters (6 to 8 feet) deep by operating the transmission in third gear at full throttle.

## 18-19. Surface Treatments to Reduce Ice Adhesion

There is a long history of study in this area for a variety of applications, but surface treatments that shed ice reliably and repeatedly have not yet emerged. The only chemical treatment that has been used successfully on a large scale for truly shedding ice is repeated application of chemicals that depress the freezing point of water. As far as concrete surfaces are concerned, the classic treatment for ice removal is repetitive application of sodium chloride or calcium chloride. Another ice-control method is a permanent or semipermanent chemical coating that reduces the adhesive force between the coated surface and the ice that

forms on it. The ideal material would be one that prevented ice formation entirely. No known coatings do this, but some make the task of ice removal from coated surfaces easier. As an alternative to coatings to reduce ice adhesion, cladding surfaces with materials that shed ice more easily than concrete may be considered.

*a. Copolymer coatings.* One successful material is a long-chain copolymer compound made up of polycarbonates and polysiloxanes. The most effective coating of the many that have been tested is a solution of polycarbonate–polysiloxane compound, silicone oil, and toluene. The mixture is highly volatile and leaves a thin coat of the copolymer and silicone on the surface to which it is applied.

(1) The copolymer coating was not to be applied to a concrete surface unless it was certain that the concrete behind the coating could resist frost action in a critically saturated condition. Proper application guidance for surface coatings to concrete can be found in *Maintenance and Repair of Concrete and Concrete Structures*, EM 1110-2-2002. The surface to be coated must be clean and dry. For concrete and metal surfaces (bare and painted), steam cleaning is sufficient; however, a detergent may be added to the water of the steam cleaner. This was done, for example, in one case where navigation lock walls were heavily coated with oil and algae. Once the surface is clean and dry, the solution can be sprayed on using an airless spray gun system (Figure 18-16). A single pass will deposit a coat 25 to 51 micrometers (1 to 2 mils) thick. Three coats are recommended for a coating thickness of about 127 micrometers (5 mils). Achieving this final thickness requires about 24.4 liters/100 m<sup>2</sup> (6 gallons/1000 ft<sup>2</sup>).



**Figure 18-16. Application of copolymer coating**

(2) Care has to be taken when mixing the solution. Toluene is a combustible material, so no electrical motor-driven mixer should be used. An air-operated drill motor fitted with a rod with mixer blades has worked satisfactorily. The fumes may also be a health hazard, so that a well-ventilated mixing area should be used. A 208-liter (55-gallon) drum fitted with a bracket to hold the drill motor is a suitable mixing container. Batches of up to 151 liters (40 gallons) can easily be handled. The liquid portions, toluene and silicone oil, are placed in the container first. Then the mixer is started and the copolymer powder is slowly

added. Mixing continues until all solids are dissolved. Then the solution can be transferred to a storage container.

(3) Tests to determine the merits of an undercoating for the copolymer (on concrete surfaces that are worn and rough) show that an epoxy-type coating that acts as a filler over the rough concrete provides a better surface to which the copolymer adheres. Trials of the undercoating and copolymer were done at the Poe Lock, at the St. Marys Falls Canal, at Sault Ste. Marie, Michigan, at Lock No. 4 on the Allegheny River, and at the Starved Rock Lock on the Illinois Waterway. Maintenance and frequency of recoating requirements were monitored. The coating remained in good condition for at least three years.

*b. Epoxy coatings.* Commercially available two-part epoxy coatings, which can be applied in wet environments, have been tested for ice-phobic characteristics. Several of these coatings perform equally as well as the copolymer coating. They are far more durable since they are an epoxy resin and a polyamine-based curing agent. The epoxy coating gives concrete ideal protection against the ingress of chloride ions, carbon monoxide, and other corrosive agents over the design life. The hard, smooth finish provides a very low friction coefficient, thus reducing the bond strength between ice and substrate.

*c. Claddings.* Cladding of wall surfaces by materials that shed ice easier than concrete is another approach to solving the problem of ice adhesion. In a demonstration at Starved Rock Lock in Illinois, a 1.2- $\times$  2.4-meter  $\times$  1.2-centimeter-thick (4  $\times$  8 foot  $\times$  1/2-inch-thick) sheet of high-density polyethylene was fastened to the curved part of the gate recess wall at the quoin end, at the ice-collar level. Hilti studs, 0.5 meters (20 inches) on center, were used for attaching the sheets. Ice formed on the polyethylene surface and the concrete surface equally, but far less effort was needed by lock personnel to manually remove the ice from the plastic material, because of the lower adhesion forces between the polyethylene and the ice. Problems were noted with ice being more difficult to dislodge where the studs protruded, but a redesigned fastening technique could overcome that problem. The polyethylene is not highly durable when pike poles or ice chippers have to be used extensively, though. The use of steam to dislodge the ice collars would eliminate the risk of this damage. The panels are easily and economically replaced, since their 1988 cost was only about \$75/m<sup>2</sup> (\$7/ft<sup>2</sup>).

## **18-20. References**

*a. Required publications.*

None.

*b. Related publications.*

### **EM 1110-2-1605**

Hydraulic Design of Navigation Dams.

### **EM 1110-2-2002**

Maintenance and Repair of Concrete Structures.

### **Nakato et al. 1992**

Nakato, T., R. Ettema, and K. Toda 1992. *Unconventional Energy Sources for Ice Control at Lock and Dam Installations*, Special Report 92-13, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

**Rand 1988**

Rand, J.H. 1988. "High-Flow Air Screens Reduce or Prevent Ice-Related Problems at Navigation Locks," *Proceedings, The 9th International Symposium on Ice*, Sapporo, Japan, 23–27 August 1988, Vol. 2, p. 34–43, International Association for Hydraulic Research.

**U.S. Army 1985**

U.S. Army 1985. "Submergible Gate Use Within the Corps: Case Histories," Report to U.S. Army Cold Regions Research and Engineering Laboratory, June 1985; prepared by U.S. Army Corps of Engineers, Louisville (Kentucky) District.